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Infiltration Model on Soil Due to the Kostiyacov and Horton Model by using Rainfall Simulator

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Abstract: ***This research intends to find the best infiltration model between Kostiyacov and Horton that focusing on the infiltration towards soil by using rainfall simulator. The soil is conducted for 3 treatments compacted soil (d_1, d_2, and d_3), however, for every compacted soil has 3 types of slope that are 2 %, 3 %, and 4%. Every trial in the rainfall simulator has the rainfall intensity of 2 l/minute. The result shows that the infiltration rate is very influenced by the compaction and slope. The higher soil compaction and slope cause the smaller infiltration rate. The mean of relative error in Horton Model is 20.365%. It is less than in Kostiyacov Model that is 29.18%. The correlation value in Horton Model is 0.844 and it is more than in Kostiyacov Model that is 0.594. This result shows that the Horton Model is better than the Kostiyacov Model in the research that is conducted with the rainfall simulator***

Keywords ***: infiltration rate, compaction, slope, relative error, and correlation value***

I. INTRODUCTION

Indonesia has long enough period of rainy season that is more than six months. This condition needs more attention because it is the basic factor to regulate an urban region [1]. The development of infrastructure is carried out for guarantying the social prosperity of society. It is also meant to change the land use and the land use change will cause rainfall cannot permeate again into soil on the rainy season [3], so it has the potency to cause surface run-off that will be becoming as pool or flood [4][5][6]. The process of infiltration and run-off is one of the urgent processes in hydrological cycle [7][8]. The development is very fast developing; it is due to the increasing of very high population economy, and tourism growth that cause some areas is covered by the water proof buildings (asphalt concrete and the like others) and it causes the decreasing of rainfall interception into soil and the increasing of surface run-off. The land use change in the interception area due to the development for residence, industry, and urban facilities are predicted has disturbed the hydrology cycle. Based on the hydrology cycle, Soemarto {9}[10] expressed that hydrology cycle is as the evaporation of sea water due to the sun radiation and cloud that is happened by water vapor above the mainland and pressed by wind. The wind pressure and the crash of water vapor will become as rainfall. The rainfall that is dropped to the land will form the run-off that returns flow to the sea. Some of them enter into soil (infiltration) and continuously moving down into saturated zone under the soil water surface or phreatic surface (percolation). Water in the soil is slowly moving through the aquifer into river or sometimes directly to the sea. Infiltration is the entering of water flow into the soil through the soil surface. This condition is very influenced by something that are rainfall intensity, soil porosity, the density of soil mass, the content of groundwater, soil texture, soil structure, soil density, and land slope. Based on the description above, the infiltration rate is influenced by the soil pores, the closer soil pores causes the smaller infiltration rate if it is compared with the soil that has the bigger pores, and the bigger pores soil has the bigger infiltration rate. The land slope is also influencing the infiltration rate. However, all of them are depended on the treatment in every area. This research intends to apply the models of Kostiyacov and Horton toward the infiltration rate on the rainfall simulator. The control of application is on the relative error and correlation value. This research is hoped can manage the urban area, mainly the urban hydrology by applying the eco drainage.

II. MATERIAL AND METHOD

The research is conducted in Tlogomas Village-Malang City and it is located in the center of Malang Regency. Tlogomas Village is in the east longest of 112.06° – 112.07° and south longest of 7.06° – 8.02° and the area is 11,055.66 ha. Map of location is presented as in the Fig. 1.

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Fig. 1 Map of Location

The taking of soil sample is carried out in Tlogomas Village where is located in Malang City. The rainfall simulator is used for carrying out the simulation in this research. Rainfall simulator is a tool that give us the possibility to see the hydrology cycle in small scale, however, there are some factors that are not entered in this tool that are evapotranspiration and evaporation.

Infiltration is water moving from the unsaturated soil surface into soil due to the gravitation and soil capillarity power. Then, the infiltration is different defined by some experts, however, if it is depth studied. The definition has the principal understanding that is almost the same such as the water moving from over into the soil surface. The maximal rate of water moving into soil is mentioned as the infiltration capacity. The higher soil compaction causes the smaller infiltration. The soil compaction can be caused by the influence of the rainfall collision on the soil surface. The determination of infiltration can be carried out through the three ways as follow: 1) To determine the different between synthetic and running rainfall in laboratory trial by using the synthetic rainfall simulation (laboratory simulation method); 2) To use the infiltrometer ring (field measuring method); 3) To use the technique of flow hydrograph separation form the rainfall (hydrograph separation method).

A. Model of Kostivacov

Model Kostiyakov uses the approach of power function by not entering the initial and final water content (when the infiltration rate is fixed) as the component of function. The function of infiltration and infiltration rate is presented as follow:

$$F = at^b \text{ , } 0 < b < 1 \qquad (1)$$

$$f = \frac{dF}{dt} = abt^{b-1} \qquad (2)$$

Where a and b is constant. However, a and b is depended on the soil characteristic and initial water content. The constant is not determined before and it is usually determined by drawing a straight line on the graphic paper for the empirical data or by using the least exponential method.

B. Model of Horton

Model of Horton is one of the infiltration models that are famous in hydrology. Horton acknowledged that the infiltration capacity is decreasing along with the increasing of time until it closes the constant value. Horton expressed that the decreasing of infiltration capacity is controlled by the factor that is operated in soil surface if it is compared with the flow process in the soil. The formula of Hortong model is as follow:

$$f = fc + (fo - fc)e^{-kt} \qquad (3)$$

$i \geq fc$ and k = constant

Where:

f = real infiltration rate (cm/h)
fc = fixed infiltration rate (cm/h)
fo = initial infiltration rate (cm/h)
k = geophysical constant

This model is very simple and it is more suitable for the trial data. The main weakness of this model is on the determination of parameters that are fo, fc, and k. They are determined with the fitting data.

III. RESULTS AND DISCUSSION

A. Analysis of soil characteristic

In this research, the sample of soil is come from the dugouts where is located in Tlogomas Village. The dugouts are taken to the Soil and Groundwater Laboratory for testing the soil specific gravity and gradation of soil granules.

B.Analysis of specific gravity

Spesific gravity is the ratio between soil weight and water weight that has the same volume with the soil on the same temperature. Based on the analysis, it is obtained the specific gravity (Gs) is 2.223.

C.Analysis of soil granular size

The gradation of soil granular size Gradasi is presented as in the Table- I.

Tabel 1. Analisis Ukuran Butiran Tanah

Location	Soil granular size (φ)			Specific gravity
	Sand (%)	Silt (%)	Clay (%)	(Gs)
Tlogomas	18.0	46.8	35.2	2.223

D. To determine the soil compaction

The compaction is designed for three variations as follow: 1) Compaction-1 (d_1), soil with the dry weight of 120 kg is added with 20% of water. Then, the soil is compacted with the pounder of 2.9 kg. The soil is compacted with 3 layers and each of layers is pounded for 2 cycles. The cycle is used to obtain the same height in every side. The soil height after compacted becomes as 13.4 cm. Then it will be obtained the value of γ_d from the compaction with 2 cycles is 0.83 gr/cm^3; 2) Compaction-2 (d_2), soil with the dry weight of 120 kg is added with 20% of water. Then, the soil is compacted with the pounder of 2.9 kg. The soil is compacted with 3 layers and each of layers is pounded for 4 cycles. The cycle is used to obtain the same height in every side. The soil height after compacted becomes as 11,5 cm. Then it will be obtained the value of γ_d from the compaction with 4 cycles is 0.96 gr/cm^3; 3) Compaction-3 (d_3), soil with the dry weight of 120 kg is added with 20% of water. Then, the soil is compacted with the pounder of 2.9 kg. The soil is compacted with 3 layers and each of layers is pounded for 6 cycles. The cycle is used to obtain the same height in every side. The soil height after compacted becomes as 10.2 cm. Then it will be obtained the value of γ_d from the compaction with 2 cycles is 1.09 gr/cm^3

E.**Parameter that influence the infiltration**

The other parameters that influence the infiltration rate are presented as in the Table- II

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Table- II. Analysis of parameters that influence the infiltration

Name	Specific gravity (Gs)	compaction (yd) (gr/cm^3)	Water content (%)	slope (%)
d_1		0.83	19.00	2
				3
				4
d_2		0.96	22.53	2
	2.223			3
				4
d_3		1.09	28.75	2
				3
				4

The measuring of infiltration rate on the rainfall simulator indicates that the infiltration rate will be continuously decreasing in line with the increasing of time. The time increasing of water ia absorbed into soil, makes the soil becomes wet and the soil will be in saturated condition, so the soil is not able again to absorb water. The relation between the infiltration rate and the compaction and slope is influenced to the time decreasing of soil to absorb water and towards the constant value of infiltration rate and it is presented as in the Table- III.

Table- III. The influence of compaction and slope to the infiltration rate

Name	slope (%)	compaction (yd) (gr/cm^3)	Constant infiltration rate (mm/mnt)
d_1	2	0.83	0.3692
d_1	3		0.2769
d_1	4		0.0923
d_2	2	0.96	0.2307
d_2	3		0.1846
d_2	4		0.0923
d_3	2	1.09	0.1846
d_3	3		0.1384
d_3	4		0.0923

Based on the Table- III, it is obtained the curve as presented in the Fig. 2.

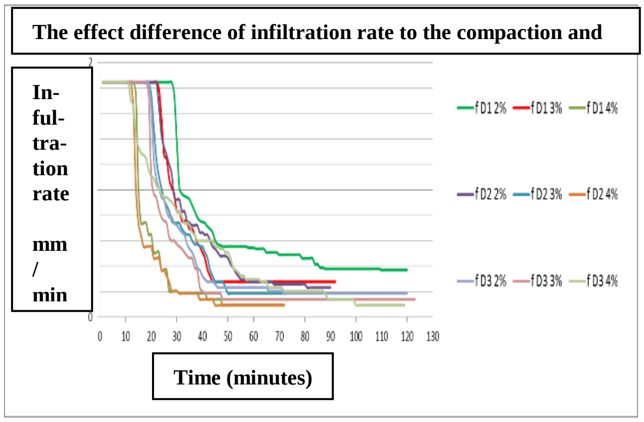

Fig. 2 The effect difference of infiltration rate to the compaction and slope

Based on the Fig. 2, the infiltration rate is influenced by the compaction and slope as follow: 1) When the compaction is the same and the slope is higher and higher that is f D1 2%, f D1 3%, and f D1 4%, the when the infiltration is constant, will be more decreasing; 2) When the slope is the same and the compaction is higher and higher that are f D1 2%, f D2 2%, and f D3 2%, so when the infiltration rate is constant, will be more decreasing; 3) When the compaction is the same and the slope is lower and lower that are f D1 4%, f D1 3%, and f D1 2%, so when the infiltration rate is constant, will be more increasing; 4) When the slope is the same and the compaction is lower and lower that are f D3 2%, f D2 2%, and f D1 2%, so when the infiltration rate is constant, will be more increasing. Fig. 3 presents the curve of infiltration rate (D3) 2%.

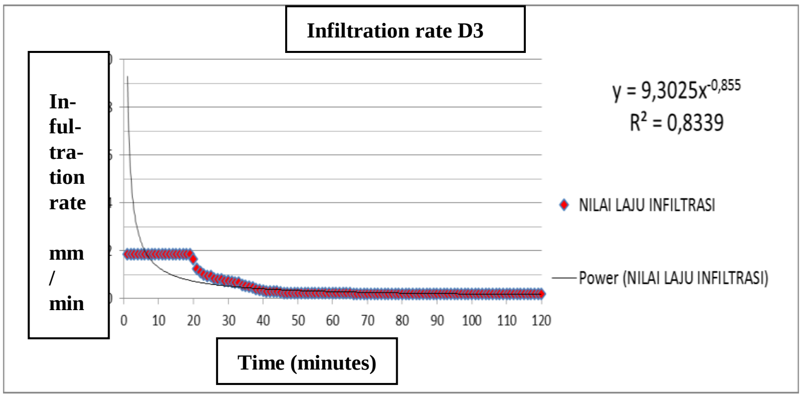

Fig. 3 Curve of infiltration rate D3 2%

The formula result is the model of Kostiyacov that is Y= $9.3025x^{0.855}$. However, for the Model of Horton has to find the value of k that is obtained from the curve as follow :

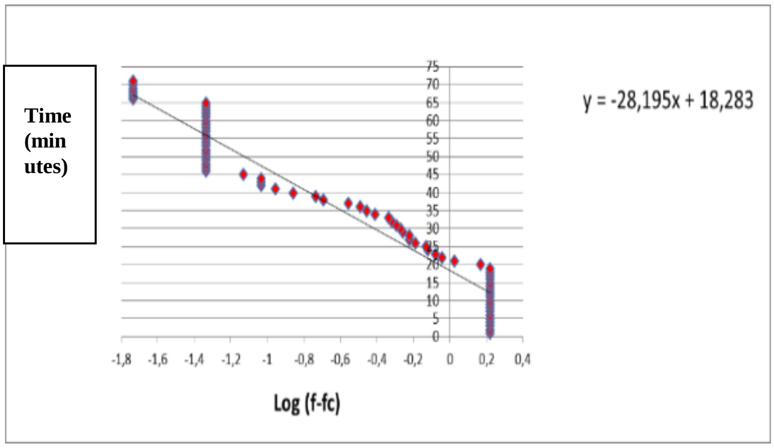

Fig. 4 Comparison curve of Log(f-fc) and time (minute)

The formula that is obtained from the curve above is Y = -28.195x + 18.283. The formula is used to find the value of k.

Then k is entered to the Model of Horton and the result is as follow:

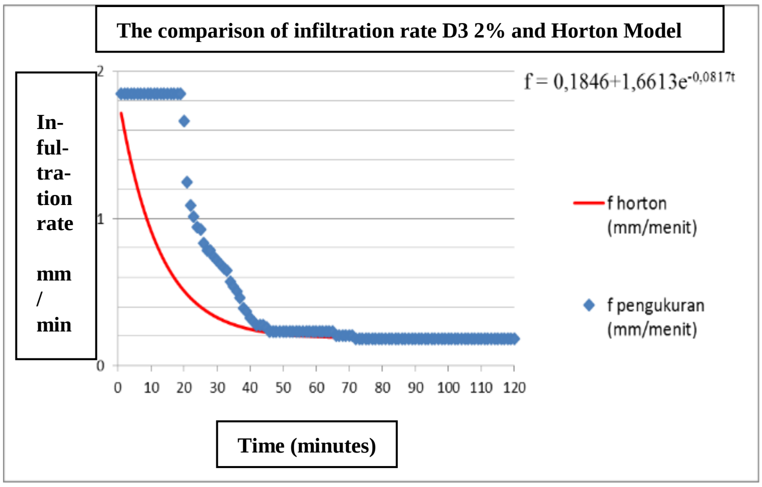

Fig. 5 Comparison curve of infiltration rate (mm/minute) and time (minute)

The analysis by using the Model of Kostiyocov and the Model of Horton, on the 120th minute is as follow;

- f calculated (mm/minute)
  $= y = 9.3025x^{-0.855}$
  $= 9.3025 \times (120^{-0.855})$
  $= 0.1552$ mm/minute
- f horton (mm/minute)
  $= f = fc + (fo - fc) \times e^{-kt}$
  $= 0.1846 + ((1.8459 - 0.1846) \times 2.718^{-0.817 \times 120})$
  $= 0.1847$ mm/minute
- KR f Kostiyocov (%)

$$= \frac{(f_{pengukuran} - f_{kostiyacov})}{f_{pengukuran}} \times 100\ \%$$

$$= \frac{(0,1846 - 0,1552)}{0,1846} \, x \; 100\,\%$$

= 15.920 %

➢ KR f Horton (%)

$$= \frac{(f pengukuran - f horton)}{f pengukuran} \, x \; 100\,\%$$

$$= \frac{(0,1846 - 0,1847)}{0,1846} \, x \; 100\,\%$$

= 0.050 %

Based on the analysis of two models above, the result is presented as in the Fig. 6.

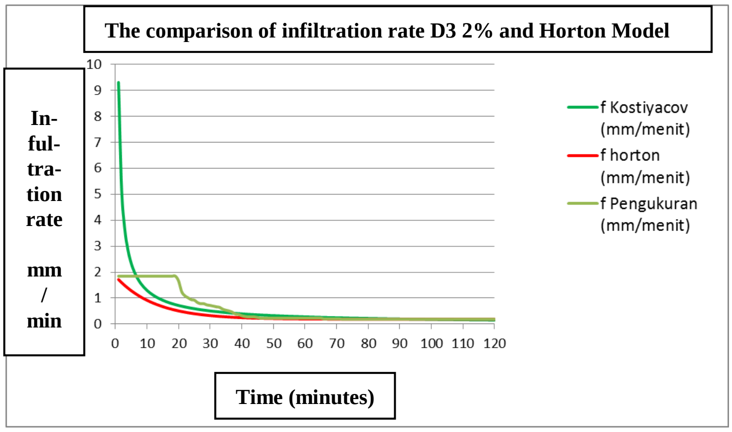

Fig. 6 The comparison curve of infiltration rate between Model of Horton and Model of Kostiyacov to the f observed

The analysis of relative error and correlation of Kostiyacov and Horton Model is presented as in the Table- I

Table- IV. Relative error and correlation

No	Name of trial	Relative error		correlation	
		Model Kostiyacov	Model Horton	Model Kostiyacov	Model Horton
1	f D1 2%	18.399%	22.347 %	0.669	0.859
2	f D1 3%	33.489%	23.969 %	0.590	0.826
3	f D1 4%	35.448%	24.853 %	0.549	0.902
4	f D2 2%	35.218%	30.255 %	0.586	0.858
5	f D2 3%	39.987%	27.199 %	0.560	0.877
6	f D2 4%	27.087%	19.341 %	0.572	0.914
7	f D3 2%	18.740%	8.980%	0.619	0.882
8	f D3 3%	28.116%	5.57%	0.588	0.847
9	f D3 4%	29.002%	20.481 %	0.612	0.988
Mean		29.498%	20.365 %	0.594	0.884

The relative error of Horton Model is 20.365% and it is less than the Kostiyacov Model (29.498%). The correlation value of Horton Model is 0.884 and it is more than the Kostiyacov Model (0.594).

IV. CONCLUSION

Based on the laboratory research about application the models of Kostiyacov and Horton towards the infiltration rate on the simulator rainfall, it can be concluded as follow:

1. The minimum and maximum relative error for the Kostiyacov Model is 18.399% and 39.987%, however, for the Horton Model is 5.857% and 30.255%. The relative error mean in Kostiyacov Model is 29.498% and in Horton Model is 20.365%.
2. The minimum and maximum correlation value for the Kostiyacov Model is 0.519 and 0.619, however for the Horton Model is 0.826 and 0.988. The correlation mean for the Kostiyacov Model is 0.594 and for the Horton Model is 0.884
3. Based on the mean of relative error and correlation, the Horton Model is as the nearest with the measuring of infiltration rate on the rainfall simulator.

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